Erodibility of Mud: Characterization and Prediction

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LONG-TERM GOALS

To improve our capabilities for measuring and predicting erosion rates, sediment flux, water clarity and bed strength in muddy coastal environments, particularly with respect to their evolution through time on tidal flats.

OBJECTIVES

The objectives of my current work within the Tidal Flats DRI are:

1) Measure temporal variations in erodibility and shear strength of tidal flat and channel sediment in Willapa Bay.
2) Measure temporal variation in consolidation and erodibility of sediment from Willapa Bay under controlled laboratory conditions;
3) Correlate temporal and spatial variations in erodibility with other sediment, channel and flow characteristics.
4) Use the results to improve formulations for mud deposition, consolidation, resuspension and net erosion in shelf sediment transport models.

APPROACH

Laboratory and field measurements of erodibility were made using a Gust erosion chamber. The erosion chamber permits shear stresses from 0.01Pa – 0.40Pa to be applied to the surface of sediment in a core tube and the resulting suspended sediment to be sampled for concentration, grain size and mass eroded. Cores were collected in the field using a hand corer that leaves the sediment-water interface undisturbed. Deposits were created in the lab by slurrying sediment from the field site with salt water and allowing the suspension to settle in a core tube. The field experiments were made in conjunction with a team of investigators who, collectively, also measured porosity, shear strength, grain size, water levels, waves, meteorological conditions, velocity and suspended sediment concentrations and properties, accumulation rates, and depositional characteristics.

The modeling extends and combines several models for the dynamics of muddy seabeds that I previously developed with ONR funding. The first is a 1-dimenionsional, steady-state shelf sediment

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transport model that includes wave-current interaction, resuspension, sediment-induced water-column stratification, evolution of graded storm beds (though not net erosion or deposition), dynamic roughness, and bioturbation. This model has been adapted to directly use the results of the erosion chamber tests to set the bottom boundary condition on sediment in suspension. The second model is similar, but is time-dependent and includes flocculation dynamics for suspended sediment and active bed consolidation (Wiberg et al., in prep.) and lacks a correction for stratification. The model is applicable to tidally dominated environments as well as open shelves and could be an ideal model to use in conjunction with the field measurements. Sanford's (2008) recent formulation for bed consolidation will be incorporated into this model. I will be using the laboratory and field erosion measurements to test and improve the characterization of consolidation and resuspension of mud deposits by tidal flows in my 1D models during the final year of the project.

WORK COMPLETED IN FY10

1. Field measurements of erosion rates in secondary channels and on tidal flats in southern Willapa Bay in late February – early March 2010.

2. Measurements of tidal elevation and wave conditions in our Willapa Bay study area from February-April 2010.

3. Processing of data for all erosion tests.

4. Hosted workshop to put erosion results, sediment properties, flow measurements, analysis of core deposits and suspended sediment data from Willapa Bay together into one comprehensive conceptual model.

RESULTS

I measured erosion rates on tidal flats and in an adjacent secondary channel in southern Willapa Bay, WA, in late February – early March 2010, extending the seasonal resolution of our earlier measurements in September 2008, March 2009 and July 2009. Measurements in winter 2010 focused on a transect that extended from B-flat, across C-channel and onto C-flat, to capture the variation in sediment erodibility across the flats, on the flat-channel margin, and within the channel (Figure 1). Measurements were also made at selected points along the channel axis, revisiting sites previously sampled in July 2009. Replicate erosion measurements were made at all sites by Brent Law.

Complimentary measurements along the transects included sediment strength (Bruce Johnson), grain size of surface sediment and eroded sediment (Brent Law), and porosity (Rob Wheatcroft). In addition, Paul Hill and Tim Milligan measured flow and suspended sediment at nearby sites on the flats and in the channel, Andrea Ogston measured flow and suspended sediment at another site in the channel and Chuck Nittrouer collected core samples from the flats and channel.
The erosion data from March 2009, July 2009 and Feb/Mar 2010 were used to address 4 questions: 1) does erodibility vary along tidal channels?; 2) does erodibility vary significantly between flats and channels?; 3) does sediment erodibility vary seasonally?; and 4) how do the results fit in the context of consolidation time-scales and forcing?

1) Along-channel erodibility was relatively constant in July 2009 with an average of 0.03 kg/m^2 of mass eroded over the course of the erosion experiments with the exception of one site (CC6) where

more than 5 times the mass of sediment was eroded compared to the mean of the other sites along the channel (Figure 2). Further investigation suggests that this core was taken on the channel flanks, a region of low strength that is also prone to slumping. Apart from the one highly erodible site, there is a suggestion of a decrease in erodibility with distance up-channel, but more samples would be needed to know if the decrease is significant. Average along-channel mass eroded in Feb/Mar 2010 averaged 0.16 kg/m^2 with no clear along-channel trend (Figure 3B). Winter values of channel erodibility are over 5 times higher than average summer values, but are comparable to the one anomalously high summer value at site CC6.

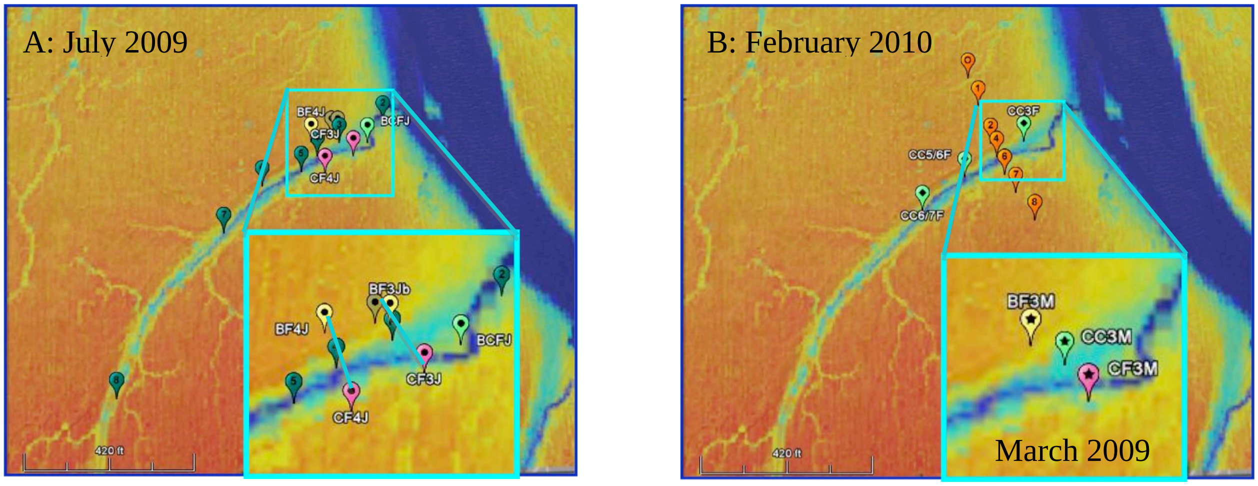

Figure 1: A: July 2009 core locations for erosion testing focused along a secondary channel in southern Willapa Bay. B: February 2010 and March 2009 core locations for erosion testing focused on a flat-channel-flat transect.

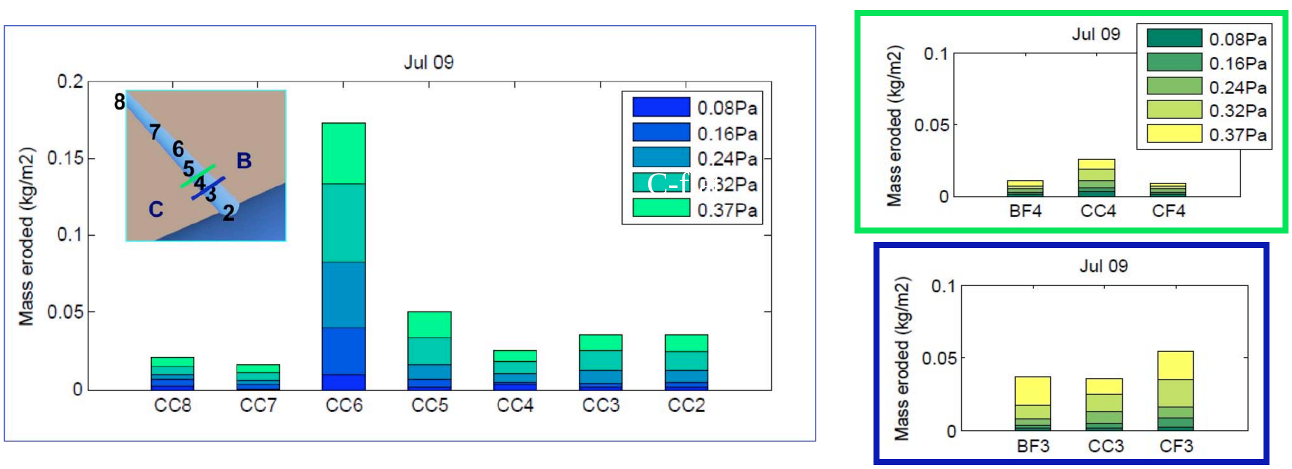

Figure 2: A. Along-channel erosion measured in summer 2009. The inset shows the site locations. The average value of mass eroded was 0.03 kg/m^2 with the exception of core CC6 (18 kg/m^2), likely taken on the channel's northern flank. B and C: Across-channel erosion measured along the green (B) and blue (C) transects indicated in the inset in Figure 2A. Erodibility of the channel and adjecent flats was similar in July 2009.

2) The flat-channel-flat transect measurements from Feb/Mar 2010 reveal a clear difference between flat and channel erodibility (Figure 3). With the exception of one flat sample (T1) flat erosion averaged 0.02 kg/m2 and was similar on both sides of the channel. Erosion in the channel thalweg and northern (B-flat) flank were roughly the same – 0.15 kg/m2, but erosion on the southern (C-flat) flank was the same as on the flat (0.02 kg/m2). Summer (July 2009) transects (channel plus one sample on each flat just beyond the flank; Figure 2B,C) do not show the pronounced channel-flat differences observed in winter 2010, although there is an indication that the flats margins on the transect closer to the channel mouth (Figure 2A inset) are more erodible than those of the transect just up-channel. There is not enough information to know whether this is a trend or a local effect. In any case, the summer flat erosion values are generally comparable to those measured in winter while the summer channel erosion values are much lower than those measured in winter 2010.

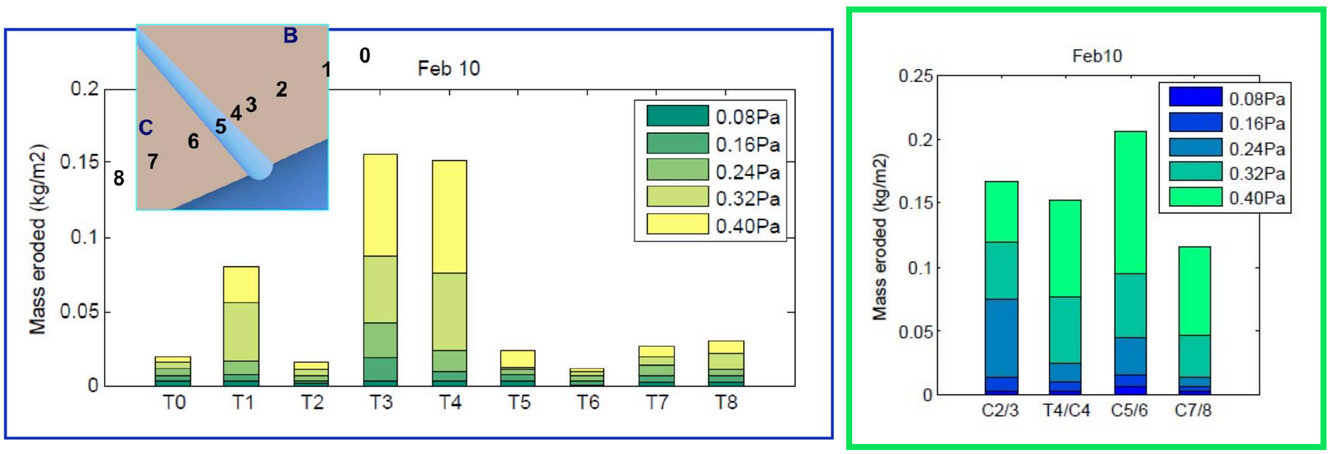

Figure 3 A. Measured erosion along a flat-channel-flat transect in winter 2010. . The inset shows the site locations. B: Along-channel erosion in winter 2010; the site labels are keyed to the inset in Figure 2A. The average value of mass eroded on the flats was 0.02 kg/m^2 with the exception of core T1. Mass eroded in the channel was much higher, averaging 0.15 kg/m^2.

3) The results shown in Figures 2 and 3 show a clear seasonal difference in erodibility, consistent with observations by other investigators based on sediment cores and measurements of porosity and suspended sediment. In combination, these data suggest a conceptual model of seasonal variations in erodibility and sediment transport potential in tidal flat-channel complexes like those we investigated in Willapa Bay. In summer, there is relatively little sediment moving around in the system owing to vegetation and microalgae on the tidal flats, low freshwater input and few storms. Only the channel flanks appear to be highly erodible. In Feb/Mar 2010, the flats continued to display low erodibilities, in part owing to the presence of microalgae. However, flat erodibility was generally similar in March 2009 when no microalgae or vegetation was observed on the flats. In contrast, sediment in the channel bottoms and on the northern flank of the channel were ~5 times more erodible in winter than summer, reflecting a transient pool of relatively unconsolidated sediment within the channel in winter.

Transforming the erosion test data into profiles of cumulative mass eroded as a function of shear stress illustrates the pronounced seasonal differences revealed in the erosion data (Figure 4A). Since mass eroded is tied to depth below the sediment surface and the shear stress for each step of the erosion measurements can be interpreted as the critical shear stress for the underlying sediment, these profiles can be used to characterize critical shear stress as a function of depth below the sediment surface. The channel and flat profile in summer is similar to the flat profile in winter whereas the channel profile in winter reflects a much greater potential for erosion (and is similar to that for the channel flank in summer, Figure 4A).

4) Field measurements of tidal water-level fluctuations and waves in the channel (in summer and winter) and on the flats (for 2 short winter periods) as well as laboratory measurements of consolidation time-scales (completed in FY09) help to put the erosion measurements in context. Estimates of the distribution of bed shear stresses due to peak tidal currents within the channel based on tidal water levels and Ogston's velocity measurements indicate a mean stress of ~1.3 Pa (Figure 4B). The presence of waves does not increase the stresses much because the water is too deep for wave motion to have much effect at the bed given the small periods of the waves (~2s). Tidal shear stresses are smaller on the tidal flats than in the channels, but waves have a more pronounced effect given the shallow water depths over the flats, resulting in mean combined bed shear stresses of roughly 1.5 Pa.

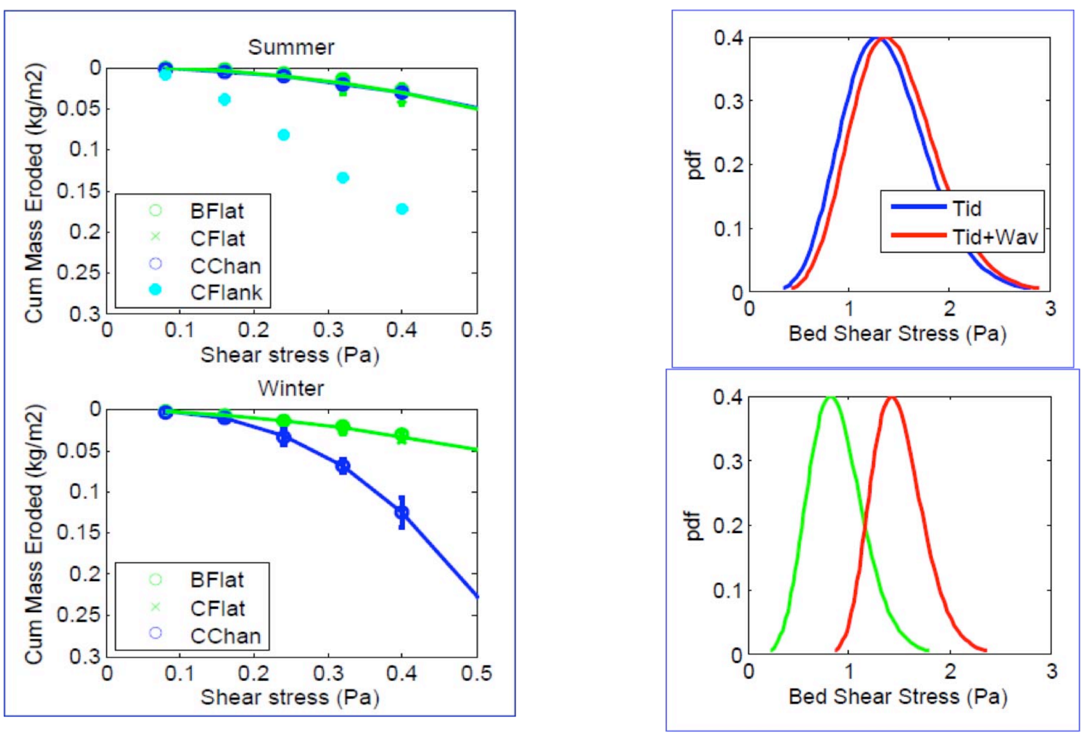

Figure 4. A: Profiles of cumulative mass eroded as a function of bed shear stress for flats and channel in summer and winter. Summer channel and flats and winter flats have the same profile. The winter channel profile and summer channel flank profile indicate much higher erosion potential at these times and locations. B: Estimated distribution of tidal bed shear stresses (blue) and tidal current + wave bed shear stresses (red) for the channel. C: Estimate distribution of tidal bed shear stresses (green) and tidal current + wave bed shear stresses (red) for the flats.

Estimates of summer and winter erosion potential can be made by extrapolating the profiles of mass eroded as a function of shear stress to the mean bed shear stresses expected in the channel and on the flats. Estimated average suspended sediment concentrations are summarized in Table 1, assuming a typical channel water depth at peak flow of 1.5 m and typical wave conditions during a wind event with a significant wave height of 0.1 m and wave period of 2 s. These results suggest that winter suspended sediment concentrations and fluxes can be 10 times greater than those in summer.

Table 1. Estimated suspended sediment concentrations at peak tidal flows

Location	*Season*	*No waves*	*With waves*
Flat	Summer and winter	0.3 g/L	0.6 g/L
Channel	Summer	0.1 g/L	0.2 g/L
Channel	Winter	>1.5 g/L	>2.5 g/L

Laboratory tests of consolidation and erodibility of channel (C-channel) and tidal flat (C-flat) sediment from Willapa Bay made in FY09 are consistent with our expectation that tidal flat and summer channel bed sediment is well consolidated. The winter channel profile, however, falls close to the consolidation profile for sediment that has been consolidating for ~48 hrs. While conditions in the lab and the field clearly differ, the results suggest that the channel bed and northern channel flank sediment are only partially consolidated.

IMPACT/APPLICATION

- Quantification of the role of spatial and seasonal variations in erodibility on tidal flats.
- Better understanding of the role of time-dependent consolidation on tidal-flat sediment erosion.
- Relationships for erosion rates that can be used in numerical models of tidal flat sediment transport and morphologic evolution.

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